

# **APPLICATION DATA SHEET**

**FOR**

## **UNITED STATES LETTERS PATENT**

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STRUCTURE AND METHOD FOR SHADOW  
MASK ELECTRODE

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# STRUCTURE AND METHOD FOR SHADOW MASK ELECTRODE

## BACKGROUND OF THE INVENTION

### *Field of the Invention*

[0001] The present invention generally relates to an interdigitated electrode structure, and more particularly to a new structure for a pair of electrodes using conductive polymers, and a method for producing the same.

### *Description of the Related Art*

[0002] An interdigitated electrode structure is used in applications where it is desirable to form a large perimeter surface area for interaction between the electrodes. Applications using this type of structure may include capacitors, sensors, and detectors. In a conventional interdigitated structure, the proximity of the electrodes is limited by a minimum lithographic feature, and hence the capacitance, or electric field intensity between the electrodes is constrained by the lithographic process.

[0003] Electronically conducting polymers, particularly derivatives of polypyrrole and polyaniline, in which the conducting form of the polymers is soluble in appropriate organic solvents, have been used in many electronic applications. These polymers can be applied onto

silicon wafers by spin-on or silk screening techniques. For example, conducting polypyrrole has been proposed as an ingredient to make passive elements such as resistors, capacitors and inductors in multichip modules or printed wiring boards, as disclosed in US Patent 5,855,755, the complete disclosure of which is incorporated by reference herein.

5 [0004] Moreover, polypyrrole and polythiophene derivatives have been used in solid state electrochromic devices. The polypyrrole conducting polymer can be made to be photosensitive by adding appropriate silver salts and photoinitiator additives, as disclosed in US Patent 5,919,402, the complete disclosure of which is incorporated by reference herein. It has been discovered that under optimized conditions, the conductivity value for poly (3-methylthiophene) is  $5.7 \Omega^{-1} \text{cm}^{-1}$ . Electrical conductivity can be further increased by incorporating metal particles such as nanoparticles of silver or copper in the polymer formulation. Thus, there is a need for an improved interdigitated electrode structure, which is capable of providing higher capacitance or electric field intensity between electrodes on electrical components of printed circuit boards and multichip modules, etc.

15 **SUMMARY OF THE INVENTION**

[0005] In view of the foregoing and other problems, disadvantages, and drawbacks of the conventional interdigitated electrode structure the present invention has been devised, and it is an object of the present invention to provide a structure and method for an improved interdigitated electrode structure. It is a further object of the present invention to increase the capacitive coupling between a pair of conductive electrodes on a substrate. The capacitive coupling will be  
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a function of the distance between the pair of electrodes, and will increase as the electrodes are brought into close proximity.

[0006] Another object of the present invention is to provide a structure for a pair of electrodes which are self-aligned to each other. The self-aligned formation of the pair of electrodes means that the patterning manufacturing process will be insensitive to variations in the positional placement of the pattern on the substrate. Still another object of the present invention is to provide a method for forming the pair of electrodes using a single lithographic masking layer where the material modification of one of the electrodes causes an overhanging region to be formed on a first electrode which is used in the formation of the second electrode.

[0007] Yet another object of the present invention is to provide a structure which consists of a pair of electrodes which are electrically isolated, yet closer in proximity than the minimum resolvable lithographic feature size of the imaging system used to pattern the electrodes. The proximity of the electrodes is determined by the chemical surface modification, and the physical deposition of the second electrode, and not by the lithographic resolution as is the case in a conventional structure.

[0008] It is still another object of the present invention to provide a structure and method for the use of a conductive polymer for one or both electrode elements in a structure where the offset between the pair of electrodes is provided by a chemical surface modification ("swelling") of the first electrode, and an anisotropic deposition of the second electrode which is shadowed by the first electrode.

[0009] In order to attain the objects suggested above, there is provided, according to one aspect of the invention a method of producing an electrode device, which comprises the steps of

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first depositing a conductive polymer material on a substrate. Then, patterning a mask on top of the conductive polymer. Third, forming spaced regions on top of the substrate. Next, the mask is removed from the conductive polymer. After which, the conductive polymer is expanded such that an upper part of the conductive polymer upwardly slopes from the lower part of the conductive polymer material. Then, a second conductive material is deposited on top of the first conductive polymer material, and in the spaced regions, which are located on the substrate. Finally, several electrical connections are placed on the device.

[0010] The benefits of this invention are several. For example, the present invention provides for a self-aligned pair of electrodes, which can be easily fabricated. Furthermore, the present invention provides for a single lithographic masking level, and for sub-lithographic features. Additionally, the structure of the present invention provides for the sub-lithographic proximity of the upper and lower electrodes.

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## BRIEF DESCRIPTION OF THE DRAWINGS

[0011] The foregoing and other objects, aspects and advantages will be better understood 15 from the following detailed description of a preferred embodiment(s) of the invention with reference to the drawings, in which:

[0012] Figure 1 is a schematic diagram of a partially completed interdigitated electrode structure according to the present invention;

[0013] Figure 2 is a schematic diagram of a partially completed interdigitated electrode structure according to the present invention;

[0014] Figure 3 is a schematic diagram of a partially completed interdigitated electrode structure according to the present invention;

[0015] Figure 4 is a schematic diagram of a partially completed interdigitated electrode structure according to the present invention;

[0016] Figure 5 is a schematic diagram of a partially completed interdigitated electrode structure according to the present invention;

[0017] Figure 6 is a schematic diagram of a partially completed interdigitated electrode structure according to the present invention;

[0018] Figure 7 is a schematic diagram of a partially completed interdigitated electrode structure according to the present invention;

[0019] Figure 8 is a schematic diagram of a partially completed interdigitated electrode structure according to the present invention;

[0020] Figure 9 is a schematic diagram of a partially completed interdigitated electrode structure according to the present invention; and

[0021] Figure 10 is a flow diagram illustrating a preferred method of the invention.

## **DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS OF THE INVENTION**

[0022] As mentioned above, there is a need for new interdigitated electrode structures capable of providing increased capacitive coupling between a pair of electrically isolated

electrodes on the substrate, where the electrodes are self-aligned to each other, are formed using a single lithographic masking layer, and are made with a conductive polymer material.

[0023] In a preferred embodiment of the present invention, the shadow mask first electrode is formed using a conductive polymer thin film material which is patterned and subjected to a surface modification to create an overhang such as that used in a conventional "liftoff" process. Surface modifications may include subjecting the first electrode (conductive polymer) to a wet chemical solvent which causes a volume expansion in the outer layer of the polymer, and hence a "swelling" along the surface of the polymer. This effect is applied to a photoresist, which is used in the well known microelectronic liftoff process. The complementary second electrode is formed by anisotropic deposition of a conductor such as physical vapor deposition (PVD) or sputtering, or evaporation from a point source.

[0024] An example of fabricating such an improved structure is shown in Figures 1-9. However, as would be known to one ordinarily skilled in the art given this disclosure, the invention is not limited to the example shown and is applicable to all similar structures. Referring now to the drawings, and more particularly to Figure 1, there are shown preferred embodiments of the method and structures according to the present invention.

[0025] Figure 1 shows a conductive polymer thin film material 20 disposed on a substrate 10. Figure 2 shows a mask 30 patterned on the conductive polymer 20 using conventional lithography and etching or by the addition of photoactive materials to the conductive polymer 20 and lithography. The conventional lithographic patterning comprises coating of a photoactive organic polymer over the conductive polymer 20. Then, exposure and development of selected regions to create a pattern of masking photoresist is performed. A dry or wet etch is then used to

pattern the conductive polymer 20. Thereupon, the masking film is removed by dry or wet processing.

[0026] Alternatively, the conductive polymer film 20 may include photoactive compounds and be directly patterned by lithography. A conductive polymer such as polyphenylenevinylene, polypyrrole, polythiophene derivatives or any other electrically conductive polymer can be used. Finally, a proper low-temperature annealing can be applied to the polymer film.

[0027] Next, Figure 3 illustrates the patterned conductive polymer 20 with narrow space region 40 and wide space region 50, which form the first electrode 25. Figure 4 shows the patterned conductive polymer 20 with the masking material removed. Again, the masking film is removed by dry or wet processing.

[0028] Patterning of the conducting polymer 20 can be done by conventional photoresist technology where a layer of photoresist of given thickness is spin coated, exposed and developed first, then the pattern is transferred to the underlying conducting polymer by reactive ion etching (RIE) the unprotected polymer. Alternatively, laser photoablation can be used to pattern the conducting polymer. In yet another integration scheme, a photosensitive conducting polymer can be used. And finally, photopatterning by electrochemical polymerization and direct nanoimprint can also be used.

[0029] In Figure 5, the conductive polymer 20 is subjected to a surface volume expansion (swelling) to create overhang regions 60 and a narrowing of narrow space region 40 to a new space 701. The phenomenon of polymer swelling upon exposure to appropriate gases or organic solvents is well known to those skilled in the art. The degree of swelling is a function of the chemical nature of variables such as the gas/solvent used, the temperature and exposure time.

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[0030] In one example, one can subject the wafer substrate, in an enclosed chamber, with a shower head facing the polymer. The chamber is first equilibrated with an inert gas such as argon or helium. Then, a stream of reactive gas is directed towards the polymer surface through the shower head for a predetermined time. An alternative approach is to have the polymer film in contact with a soft pad pre-soaked with the swelling organic solvent. When the desirable overhang is reached, the silicon wafer is removed and electrodes can be deposited as shown in Figure 6. Yet another approach is to incorporate a co-polymer into the conducting polymer blend. The chosen co-polymer will undergo an irreversible swelling due to de-polymerization upon exposure to an appropriate chemical while leaving the conducting polymer network unchanged. This last approach offers a wider choice of material that can be surface modified.

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[0031] Figure 6 also shows the anisotropic deposition of a second electrode material 81 on the upper regions of the first electrode 25, which combines with the first electrode 25. Moreover, a second electrode material 80, which is made of the same material as the second electrode material 81, is also deposited in the complementary regions 90 and gap 50 to form the second electrode 80. The second electrode material 80, 81 is comprised from a conductive material such as aluminum, copper, titanium, titanium nitride, sputtered tungsten, and is deposited by evaporating, sputtering or physical vapor deposition.

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[0032] Figure 6 best illustrates the purpose of the novel aspects of this invention, namely incorporating the surface volume expansion to electrode manufacturing. The purpose of the surface volume expansion is to ensure that there is proper spacing between the first electrode 25 and the second electrode 80. Thereby, ensuring that the electrodes are electrically isolated. Because the second electrode material 80, 81 is deposited by anisotropic deposition, the second

electrode material 80, 81 only adheres to the exposed horizontal surfaces of the substrate. Thus, when the upper regions of the first electrode 25 swell, it prevents the second electrode material 80, 81 from being deposited in the space 701, which again, ensures that the electrodes are electrically isolated. Therefore, the electrodes are self-aligned because only one lithographic mask 30 (shown in Figure 2) is used to pattern both the first and second electrode.

[0033] Figure 7 shows a top-down view of a pattern for the first electrode 25, with the cross section view a-a indicated for Figure 5. Figure 8 shows the top-down view after the deposition of the second electrode material 80 with electrical connection 100 and 110 indicated. The cross sectional area defined by the line b-b is shown in the cross sectional view of Figure 6. Figure 9 shows a top-down view with a plurality of electrode fingers provided to enlarge the perimeter between the two electrodes, and hence enhance electrical interaction between the two electrodes. Electrical connections 120 and 130 are indicated as well.

[0034] Figure 10 illustrates the flow diagram of the entire process. Step 100 indicates that a first conductive polymer material is deposited on a substrate. Then in step 102, a mask is patterned on top of the first conductive polymer. Next, step 104 shows that spaced regions are formed on top of the substrate. Step 106 follows by removing the mask from the first conductive polymer. The next step is step 108, in which the upper region of the first conductive polymer undergoes surface volume expansion. Finally, in step 110, a second conductive material is deposited on top of the first conductive polymer and on the spaced regions on the substrate.

[0035] It is apparent that the pattern of the second electrode will be the complement of the pattern of the first electrode, and that the second electrode will be self-aligned with respect to the first electrode. In addition, the spacing between the two electrodes will be determined by the

chemical surface modification of the first electrode, and not by a photolithographic patterning, and hence the proximity of the two electrodes will not be constrained by the lithographic process capability.

[0036] As previously mentioned, the benefits of this invention are several. For example, the present invention provides for a self-aligned pair of electrodes, which can be easily fabricated. Furthermore, the present invention provides for a single lithographic masking level, and for sub-lithographic features. Additionally, the structure of the present invention provides for the sub-lithographic proximity of the upper and lower electrodes.

[0037] While the invention has been described in terms of preferred embodiments, those skilled in the art will recognize that the invention can be practiced with modification within the spirit and scope of the appended claims.